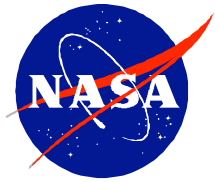
Air Force Research Laboratories /
Air Vehicles Directorate
Air Force Office of Scientific Research

Collaborative Center of Control Science

Kevin M. Passino

Director

The Ohio State University



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Welcome…

- Welcome to guests / colleagues!
- Thanks to AFOSR and AFRL-VA for funding, DAGSI for cost-share
- Thanks to Ms. Stella Rubia for 2007 CCCS Final Review assistance
- Resources:
  - Final Performance Report (leveraged funding, papers, etc.), Appendix: Slides of talks
  - Paper e-archive

Outline

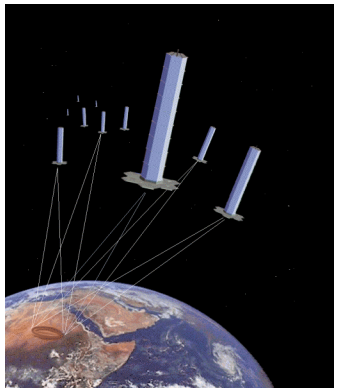
- Logistics (agenda)
- Mission, objectives, team overview
- Financial (cost share, leveraging, synergies)
- Professional+technical presence
- Brief technical overview, connections to AFRL
- Concluding remarks

CCCS Mission

Collaborative Center of Control Science +

AFRL-VA Control Science Center of Excellence

= Team of World-Class Researchers for…



Developing innovative and practical solutions to challenging control science and technology problems of highest interest to the United States Air Force

Main Objectives

1. World-Class Center: CCCS + AFRL/VA Control Science Center of Excellence (CSCOE) (proximity facilitates collaboration, collaboration enhances USAF relevance)
2. Focus on key USAF topics (balance CSCOE and CCCS research)
3. Meeting AFRL *agile workforce* objectives (STW-21)
4. Leveraging / synergies with other programs

CCCS Executive Board (2006)

- Dr. Don Paul, Chief Scientist, AFRL-VA
- LtCol. Scott Wells, Program Manager, AFOSR
- Dr. Marc Steinberg, NAVAIR and ONR
- Dr. Randy Zachery, ARO
- Dr. Kevin Wise, Lead, UCAV Mission Management, The Boeing Company
- Dr. Jim Buffington, Technology Lead, Flight Control / Vehicle Management Systems, Lockheed Martin Aeronautics Company
- Dr. D. Brett Ridgely, Senior Manager, Dept. Autopilot Design, and GNC Tech. Director, Raytheon
- Prof. Richard Murray, Division Chair, Engineering and Applied Science, Caltech (head of Board)
- Prof. Jonathan How, Dept. of Aeronautics and Astronautics, MIT
- Dr. Siva Banda, Leader, Control Science Center of Excellence, AFRL-VA
- Prof. Kevin Passino, Director, CCCS, Dept. Electrical and Computer Engineering, OSU

Team=AFRL-VA COECS+…

- Prof. Jose B. Cruz
- *Prof. Hitay Özbay*
- Prof. Ümit Özgüner
- Prof. Kevin M. Passino, Director
- Dr. Keith Redmill
- Prof. M. Samimy
- Prof. Andrea Serrani
- *Prof. Bruce Weide*
- *Prof. R.K. Yedavalli*
- Prof. Stephen Yurkovich
- Ms. Stella Rubia, Prog. Coord.

- Prof. Raúl Ordóñez (UD)
- *Prof. Marios M. Polycarpou (UC)*
- *Prof. Ali Minai (UC)*
- *Prof. Trevor Williams (UC)*
- *Prof. David Jacques (AFIT)*
- *Prof. Meir Pachter (AFIT)*

DAGSI Cost share

Italics=not funded in past year

OSU/AFRL Collaborations…

- Visits, both ways… (seminars, meet with students, etc.), Six Month Reviews, Annual Reviews, and at conferences
- Proximity clearly helps
- Placements at AFRL+OSU (e.g., AFRL: Summer 2003, S.Waun and B. Moore; Summer 2004, K. Groves, J. Malone; Summer 2005, J. Parker, R. Schultz, OSU: T. Shima 2 days/week; Summer 2006, Pete Jankovsky)
- AFRL is clearly impacting university research (making more relevant, access to simulations/expertise)
- Universities are clearly impacting AFRL (e.g., joint publications, simulation code mods/expertise)
- Universities offering nice bridges between AFRL directorates (e.g., Sensors Directorate, J. Layne+)

Financial, Cost Share

- $500K/yr AFOSR + $500K/yr AFRL-VA, 6yrs
- Support, 2004-2007: 7 faculty, 1/5 res. scientist, software eng., 3 post-docs, 8 grad students, 1/4 prog. coord.
- Cost share:
  - 9 graduate students from Dayton Area Graduate Studies Institute (DAGSI), State of Ohio till end of third year ($450K); 4 graduate student stipends per year for each of the 3 years in the 2004-2007 contract period ($254K)
  - OSU cost share on graduate student tuition and fees on all graduate students (UC, UD similar) first three years ($450K), Univ. cost share second three years ($489K)
  - Program coordinator: OSU Dept. Elec & Comp Eng., 1/2 + DARPA MICA 1/4 (OSU EE Dept. $28K), ECE 3/4 ($34K)
  - OSU Dept. Elec & Comp Eng., CCCS physical space: Cooperative control test bed, CCCS offices/meeting area/visitor space ($25K)

Cost share total=$1.73M

Leveraged Funding (samples, see report)

- NASA Glenn: Active Noise Control in High Speed Jets Using Plasma Actuators, M. Samimy, $250K
- Air Force/*SIBR*: Development of High Frequency Flow Control for Mitigation of Aero-optic Distortion, Samimy, $333K
- NASA Glenn: Jet Noise Mitigation Using Plasma Actuators, M. Samimy, $330K
- DAGSI/AFRL: Flow Control Design, Samimy/Serrani, $182K
- Intelligent Automation Corp (Navy/Army/*SIBR*): Cooperative vehicle control and pursuit-evasion games, J. Cruz, 2 phase 1, $210K + $225K (2 phase 2 contracts)
- AFRL: Control and Navigation of Air Vehicles, R. Ordonez, $50K

Leveraged Funding (samples)

- DARPA LAGR/NIST: Learning for autonomous robots, Passino, $50K
- General Dynamics: Cooperative Operations in Urban Terrain (AFRL, COUNTER), Ozguner, $42K
- AFRL (RASER): Robust data alignment, Ozguner, $33K
- MRLets Technologies (sub. from AFRL-SN): Tracking of mobile systems and hospitability map concepts", U. Ozguner, $25K
- Orbital Research (*SIBR*): Novel, biologically inspired integrative architecture for ultra-tightly coupled GPS/INS, U. Ozguner, $28K
- DAGSI (other) and OSGC Fellowships…

Funding/ additions/ leveraging, testbeds... (samples)

- AFRL-VA: Cooperative Control Testbed, $30K + $255K
- Osh Kosh Truck, Allied Signal, Honda, OSU: DARPA Grand Challenge: Ü. Özgüner, 2004: $560K; 2005: $250K
- AFRL-VA: Flow Control Testbed, $50K
- DURIP: Equipment for Flow Diagnostics and Control, M. Samimy, $444K
- NASA Glenn: Flow control, J. DeBonis (time, not included in total)

Leveraging total=$5.54M

Leveraging + Cost Sharing Total=$5.54+$1.73=$7.27M>$6M

Funding, Synergies (samples)

- DARPA MICA Program: Strategies for Human-Automaton Resource Entity Deployment (SHARED), J. Cruz, PI, $2.4M
- NASA Goddard: Solar Radiation Pressure and Formation Control in Highly Elliptical Orbits, T. Williams, $410K
- NIST: Real-Time Control Systems, K. Passino, $200K
- DAGSI/AFRL: Development and Application of High Bandwidth and Amplitude Fluidic Actuators for High Speed Flow Control, M. Samimy, $210K
- State of Ohio: Ohio Center for Advanced Propulsion and Power (OCAPP), M. Samimy, $1,350K.

Synergies total=$4.57M

Impact?

- UAVs:
  - Second to third generation UAV research
  - MultiUAV simulation code, Matlab, Networked UAVs (AFRL improvements, NASA and AFRL-MN use)
  - Spawned ideas into research community, international
- Flow Control:
  - DAGSI/AFRL-NASA synergies
  - DURIP established world-class OSU flow control lab
  - NASA Glenn contributes significant time/expertise
- RLVs: Working on establishing collaborations and expanding funding in this area (e.g., NASA, NSF, DAGSI)

Most Important Product: Students

Name	Degree granted	Post-degree affiliation	Research Support
Andrews, Burton	MS	PhD program, Johns Hopkins	Ohio Space Grant Fellow
Baum, Michael	MS		DAGSI
Bohn, Christopher	PhD	AFIT	USAF
Caraballo, Edgar	MS	PhD program, OSU	DAGSI, CCCS
Chien, Andy	MS		CCCS
Chen, Xingping	PhD		CCCS
Dagci, Oguz Hasan	MS		DAGSI
Dankwa, Boakye	MS	MS program, UD	AFRL, CCCS
Finke, Jorge	MS, PhD	Post-Doc, OSU	CCCS
Fiorentini, Lisa	PhD Student	PhD program, OSU	CCCS
Flint, Matthew	PhD	Alpha Tech	CCCS
Ganapathy, Sriram	MS	General Motors, Research and Development Laboratory	DAGSI
Gumussoy, Suat	PhD Student	MIKES Inc.,Turkey	CCCS
Groves, Kevin	MS	Harris Corporation	DAGSI, CCCS
Jankovsky, Pete	MS	Procter and Gamble	CCCS
Jennings, Alan	MS	MS program UD	DAGSI
Jiang, Zhesheng	PhD	PhD program, UD	DAGSI, CCCS
Jin, Yan	MS	PhD program, UC	DAGSI
Kanchanavally, Shreecharan	MS, PhD (UD)	Whirlpool, St. Joseph, MI	DAGSI, CCCS
Kasnakoglu, Cosku	MS	PhD program, OSU	CCCS
Kassas , Zaher	MS		CCCS
L. (Chynthia) Xu	PhD		CCCS
Li, Dongxu	PhD	OSU	CCCS
Li Wenfei	MS	PhD program, OSU	DAGSI
Liao, Yan		PhD program, UC	DAGSI
Lilly, Aromal	MS		CCCS
Little, Jesse	MS	PhD program, OSU	DAGSI, CCCS
Liu, Yanfei	PhD	Caterpillar Corp.	CCCS
Luo, Yu			CCCS
Maddula, Theju			DAGSI
McWilliams, George	MS		CCCS
Mitchell, Doug	MS		AFRL/SBIR
Moore, Brandon	MS, PhD	Job search now	DAGSI, CCCS
Ogras, Umit	MS		CCCS
Parker, Jason	MS	AFRL-SN, Wright-	NSF Fellowship

Name	Current affiliation	Research Support
Debiasi, Marco	Temasek Laboratories, National University of Singapore	CCCS
Efe, Onder	TOBB University, Turkey	CCCS
Gil, Alvaro	Xerox Corp	CCCS
Kim, Kihwan	OSU	CCCS
Liu, Yong		CCCS
Yan, Peng	Seagate Research Center	CCCS
Tang, Zhijun	Eaton Corp., Eaton Innov. Center	CCCS

Much work finishing up with PhD students and Post Docs…

Professional and Technical Presence

- Publications: See performance report + web
- Journal, Conf. Papers, Book chapters, Invited Sessions (e.g., CDC'03 & CDC'04, Cooperative Control for Networked Uninhabited Autonomous Vehicles I&II, Passino-Sparks, CDC'05 papers)
- CCCS part of "Control Research Laboratory"; long tradition of theory/experimentation, internationally recognized faculty in ECE, Aero, ME [more expertise available, smart structures, engine control, FDI, sliding mode control]

International Reputation, Reach-out

- Control Research Laboratory (CRL)
  - 7 faculty + other depts + excellent sig. proc. group
  - Workshops/conferences/service (Ed., Gen./Prog. Chair)
  - Publications, books, honors (Fellows, Nat. Acad. Eng.)
  - >30 graduate students in ECE, facilities
  - Extensive curriculum (e.g., wide range of theory, cooperative robotics lab, decentralized control lab)
- Significant *additional* funded research… [>$7M]
  - Center for Automotive Research and…
  - Int. Trans. Sys. (CAR-IT), DARPA Gr/Urb Challenge
  - Many additional projects, visitors

AFOSR+AFRL-VA bought into a large, successful, and well-established program

CCCS Visitor Program / Seminar Series

- CCCS visitors/experts in main topical areas+
  - UAVs: M. Pitarys/J. Kenney (AFRL-Boeing), D. Castañón, J. Buffington (Lockheed), R. Beard, F. Bullo, A. Fax (Northrop Grum.), S. Jayasuriya, D. Ghose, N. Leonard
  - Flow control: D. Williams, C. Rowley, J. Borggaard, L. Cattafesta, B. Noack, D. Rempfer, G. Tadmor, M. Glauser, Tinney, Krstic, Karagozian
  - RLVs: J. Zhu, J. Hanson (NASA), D. Schmidt, A. Teel, A. Isidori
- International Visitors+Collaborators:
  - Air Force's Window on Sci.: Dr. Bernd Noack of Tech. Univ. of Berlin, Germany, Jan. 2004
  - O. Efe, TOOB Univ Sci Tech, Turkey
  - H. Ozbay, Bilkent U, Turkey
  - Tomonari Furukawa, U New South Wales, Australia
  - L. Rogondino, Univ. Pisa, Italy
- Visiting Scholar, US: Z. Jin (Caltech)

Reach-Out, Industry/Government

- CCCS Annual Review (85-100 attendees / year) helps with reach-out
- Visitors:
  - Government: AFRL (VA, SN, ENY, MNGN), NASA, DARPA, USAF Academy, AFOSR, NAVAIR, ARO, ONR/NAVAIR, AFIT, NRC, NSF, Southwest Research Inst.
  - Companies: Boeing, Lockheed, Raytheon, Draper Labs, Barron Assoc., Scientific Systems Co., Orbital Research, Intell. Automation, Inst. Sci. Res.
  - Universities: UCLA, MIT, Caltech, Boston Univ., Texas A&M, Ohio Univ., Notre Dame, Univ. Michigan, Univ. Florida, Univ. Pisa,…

Reach-Out: Reviews/Overviews

- CCCS Overview, AFOSR Contractor's Workshops, 2002, 2003, 2004, 2005, 2006
- CCCS Review, Dr. Lyle Schwartz, Director, AFOSR, April 18, 2003
- CCCS Review, Dr. Belinda King, Program Manager, AFOSR, June 16, 2003
- CCCS Report, Gen. Nielsen, AFRL, June 17, 2003
- CCCS Overview/poster, AFOSR SAB Review, 2003
- CCCS Overview in AFRL-VA SAB Review, 2003, 2005
- CCCS Research Summary, DAGSI Legislative Open House, State of Ohio Senate, Nov. 30, 2004
- CCCS Overview, AFRL-VA: Dr. Brendan Godfrey, Director, AFOSR, Oct. 2004; Gen. Lamy Aug. 2005
- CCCS Overview, AFOSR Corporate Board, Sept. 29, 2005

Lessons learned… challenges…

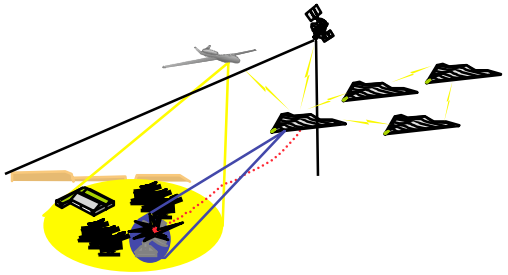
- Flexibility difficult for OSU and AFRL (e.g., in establishing new programs, de-emphasizing or eliminating others)
- Director's discretionary funds necessary (e.g., to enhance visitor's program, seed new initiatives)
- Visiting scholar opportunities are significant

2006 Executive Board Feedback

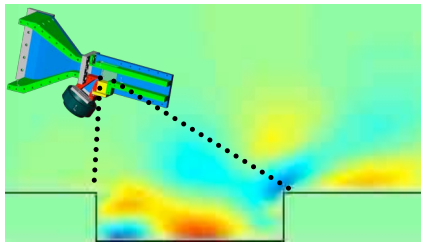
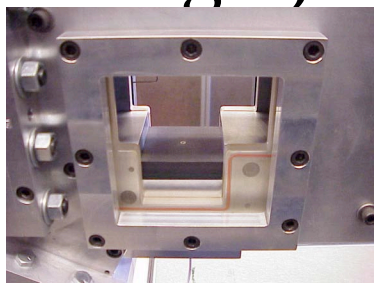
- Collaboration, Professional-technical presence, and leveraging maintained/developed as expected
- "Should pave way for next set of programs" (e.g., UAV work with C. Schumacher, RLVs)
- "Integrate UAV work" (past years, several ways)
- Increased visitor program (see report)
- Specific technical objectives: Continue to be on track as you will see…

Technical Overview

- Cooperative Control (40% budget)



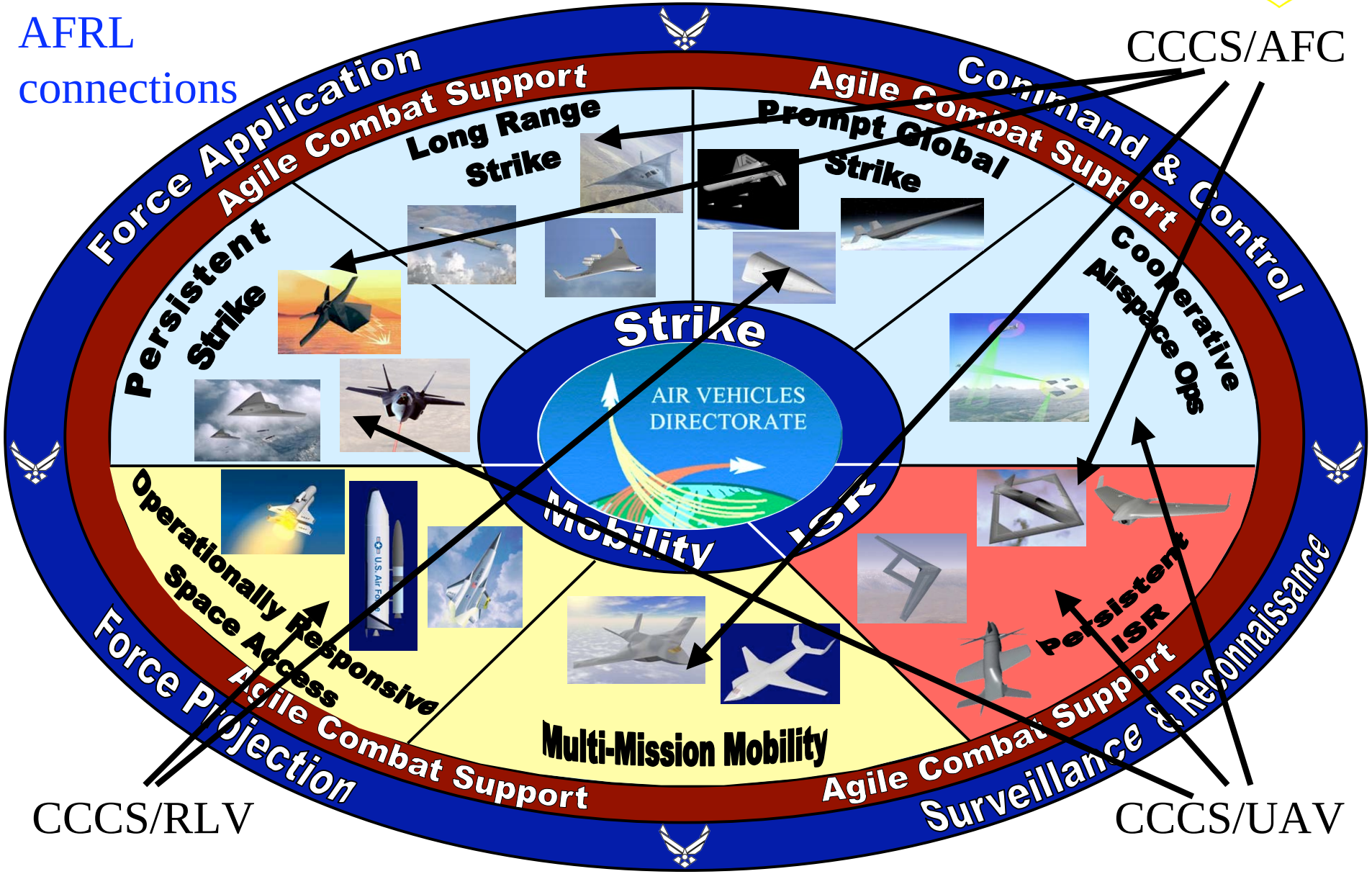
- Aerodynamic Flow Control (40% budget)

- Reusable Launch Vehicles (20% budget)


Capability Focused Tech Investment

AFRL connections



CCCS/AFC

CCCS/RLV

CCCS/UAV

Concluding Remarks

- CCCS finishing, second-third generation research, *now a leader in aerospace control systems*
- CCCS/AFRL-CSCOE collaboration went well, with clear evidence:
  - Technical program coordination/re-orientation
  - Serving as AFRL collaboration focal point
  - Publications (joint)
  - Cost share/leveraging, synergies with other programs
  - Visitors/seminars
  - Professional-technical presence